TFPX Phase 2 Mechanics Studies With tkLayout

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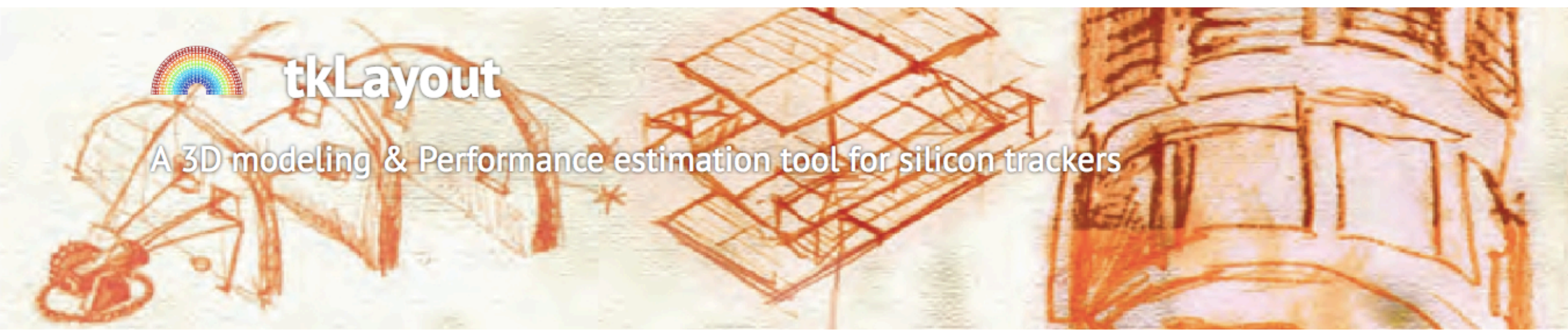
Outline

- tkLayout overview
- TDR geometry
- Tweaks in mechanics
- Tweaks in material

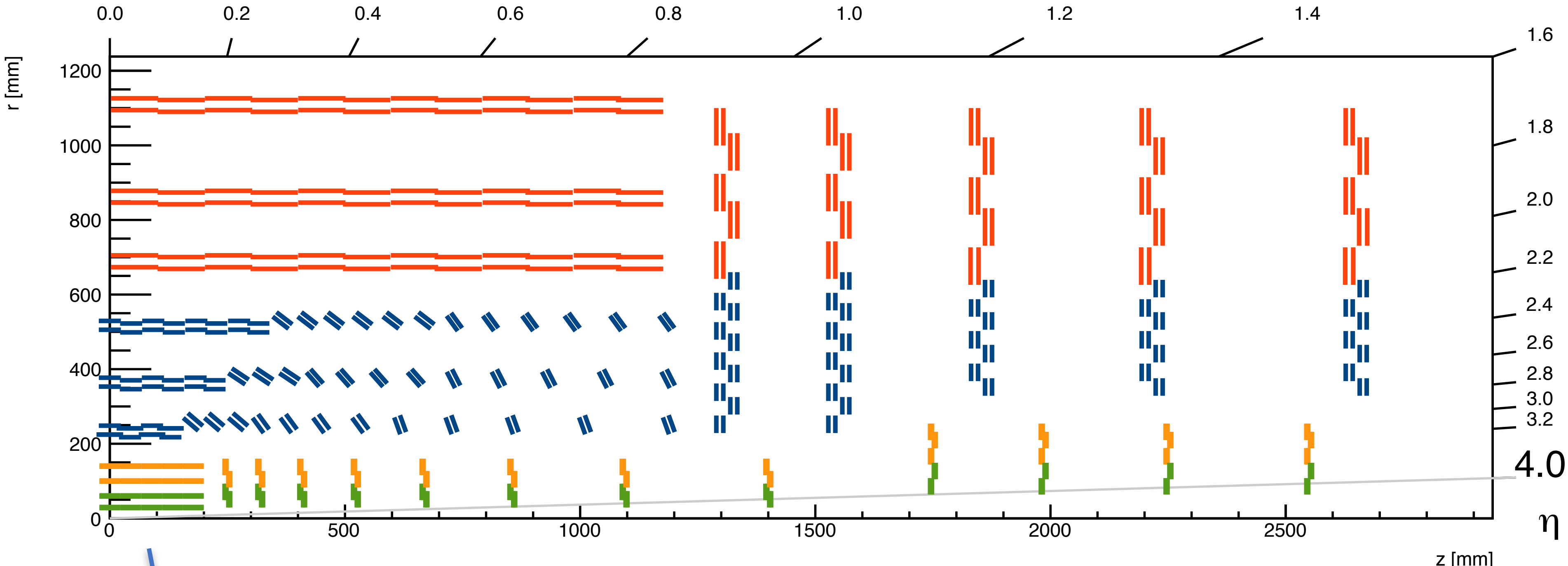


http://tklayout.web.cern.ch/

tkLayout overview

- Tool developed at CERN to simulate silicon tracker detectors
- Runs much faster than the full CMS MC simulation
- Parametrization of resolutions, not full MC
- Also gives the total material budget and radiation length estimate
- Geometry and materials are specified as 2D surfaces
- Purpose is to facilitate fast(er) prototyping
- Not as accurate as MC, but especially useful to compare geometries relative to each other

TDR layout



8 TFPX disks

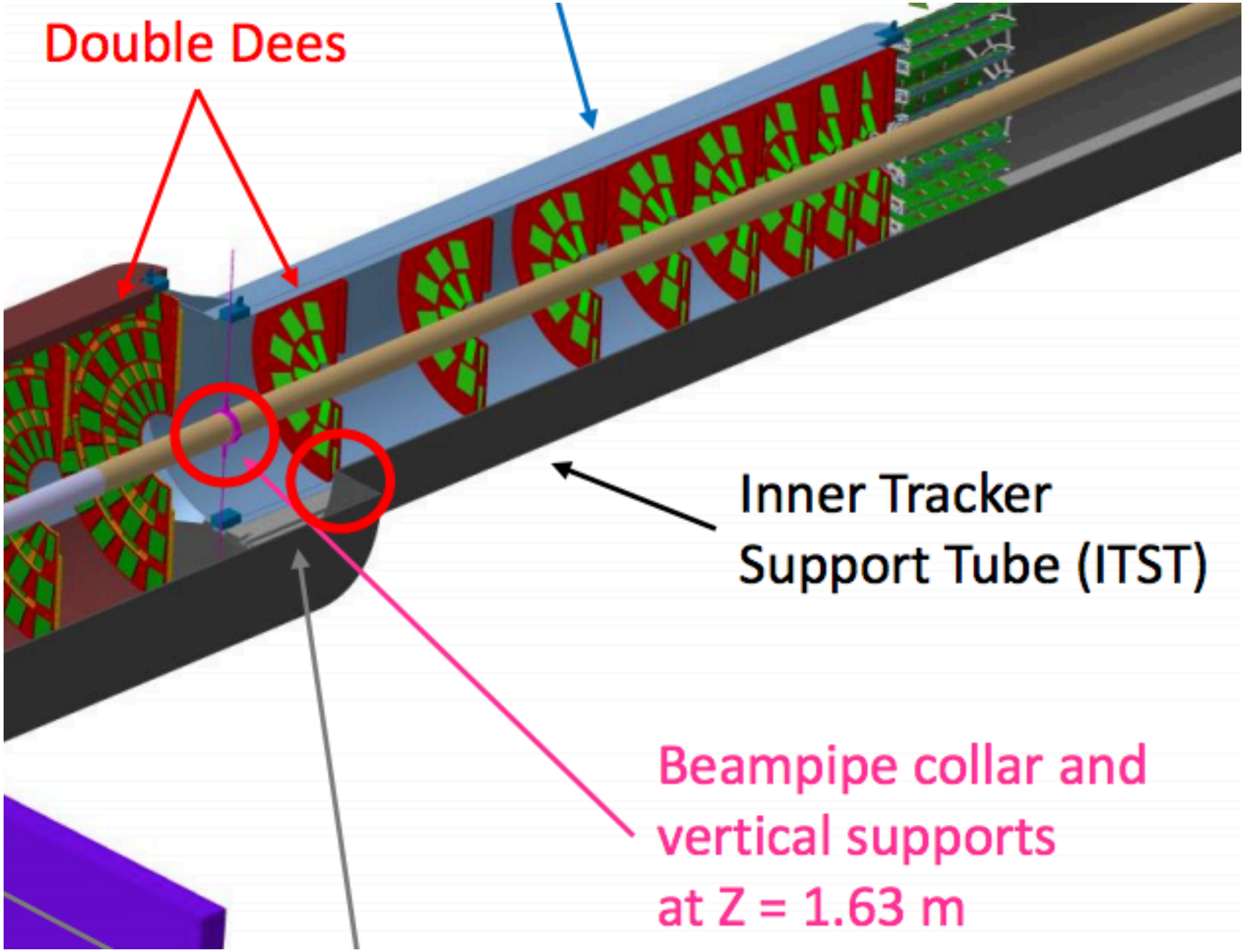
4 TEPX disks

4 TBPX layers

Tweaks in mechanics

- To accommodate mechanical engineering and beam installation clearance issues, a few tweaks to the TDR geometry have been studied in tkLayout
- The tool is useful for precisely these modifications, where we can compare the 'baseline' geometry with the new ones to see how the physics is affected relatively
- Shown here is some disk Z spacing adjustment and a ring inner radius adjustment

Installation clearance issues



Talk by Annti Onnela, Indico: 630403

Installation clearance issues

Modifications needed in the TFPX

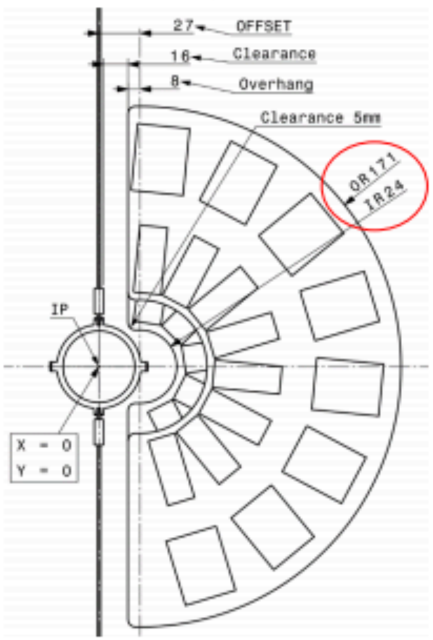
Link to 2017_09_21 Double Dee Design

- The TFPX Dees' IR is currently 24 mm, leaving only 1.5 mm clearance to the Beam-pipe (OR 22.5 mm)
- And, for the IT installation even larger increase is needed, to allow TFPX to properly pass the Beam-pipe support collar (OR 27.5 mm).

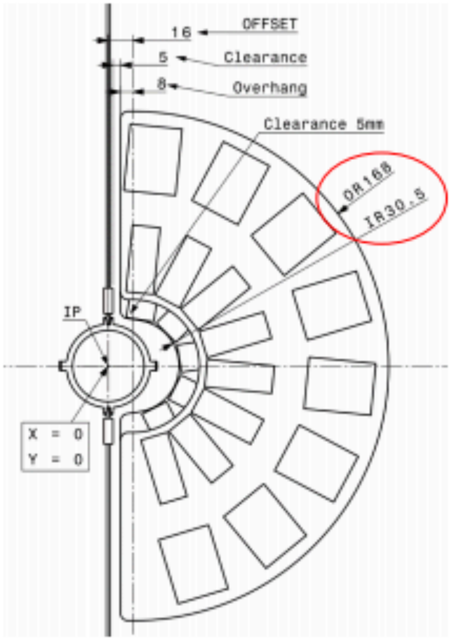
→ The respect the needed clearances the IR of the TFPX Dees needs to be increased to 30.5 mm.

→ And to match with the space available on the outer periphery the Dee OR needs to be reduced to 168 mm.

TDR design



Proposed, compatible design



Difference: 4 mm

Module radius difference: 2 mm

IT-OT Boundary & envelopes, indico: 630403 23

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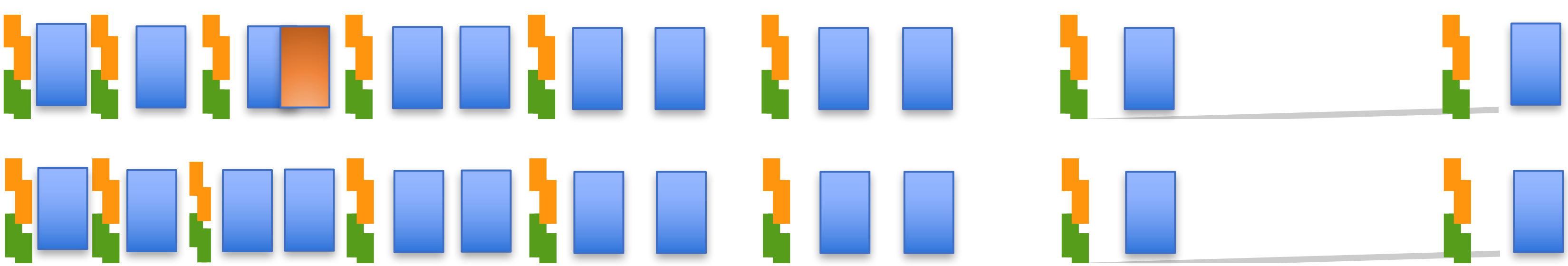
TBPX services issue

- Yadira needed some space inside and on the service cylinder for placement of TBPX services
- Based on 'cartridge' idea of placing converters and adapters on easy-to-swap cartridges interspersing with double-dee disks
- Both TBPX layers and TFPX disks require cartridges
- In order to make space for TBPX cartridges, Z position of third disk needs to be moved:

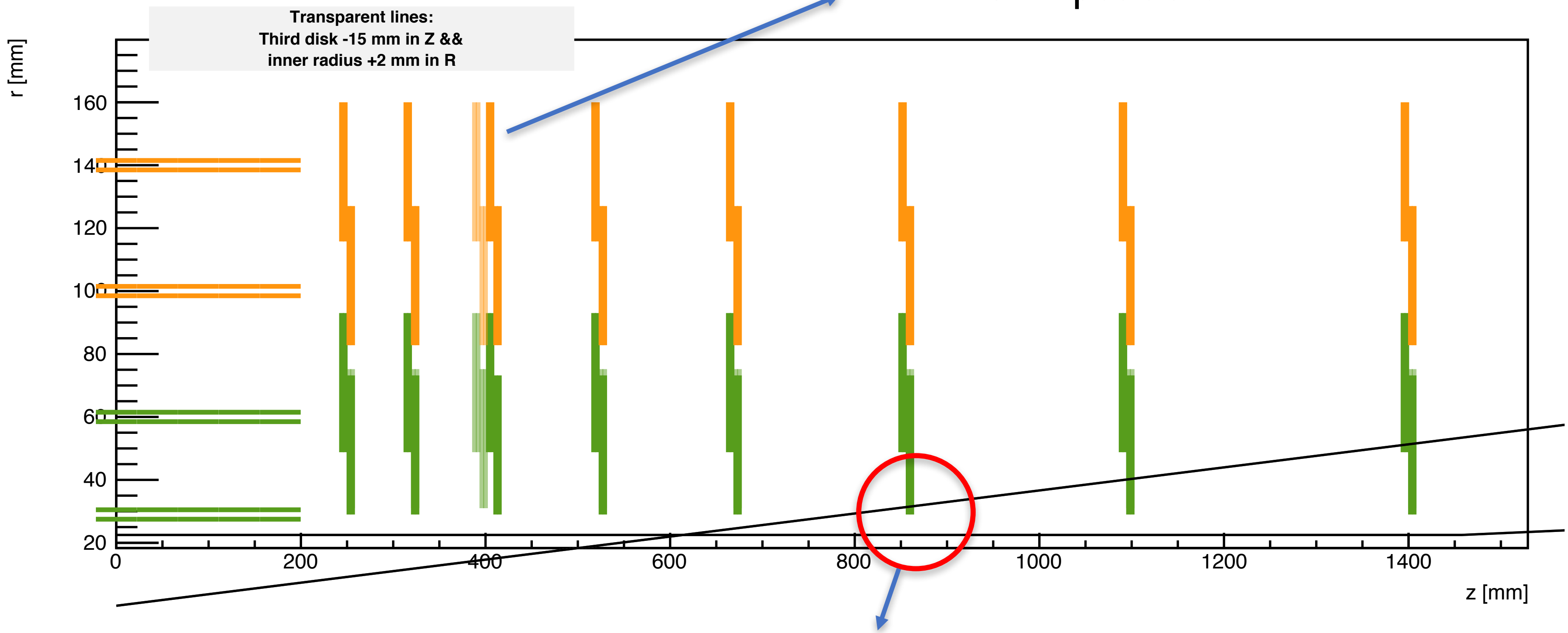


Sketch representation only!

Geometry modifications

- Differences are Z position of third disk and R position of innermost rings (semi-transparent positions are new versions of solid ones)

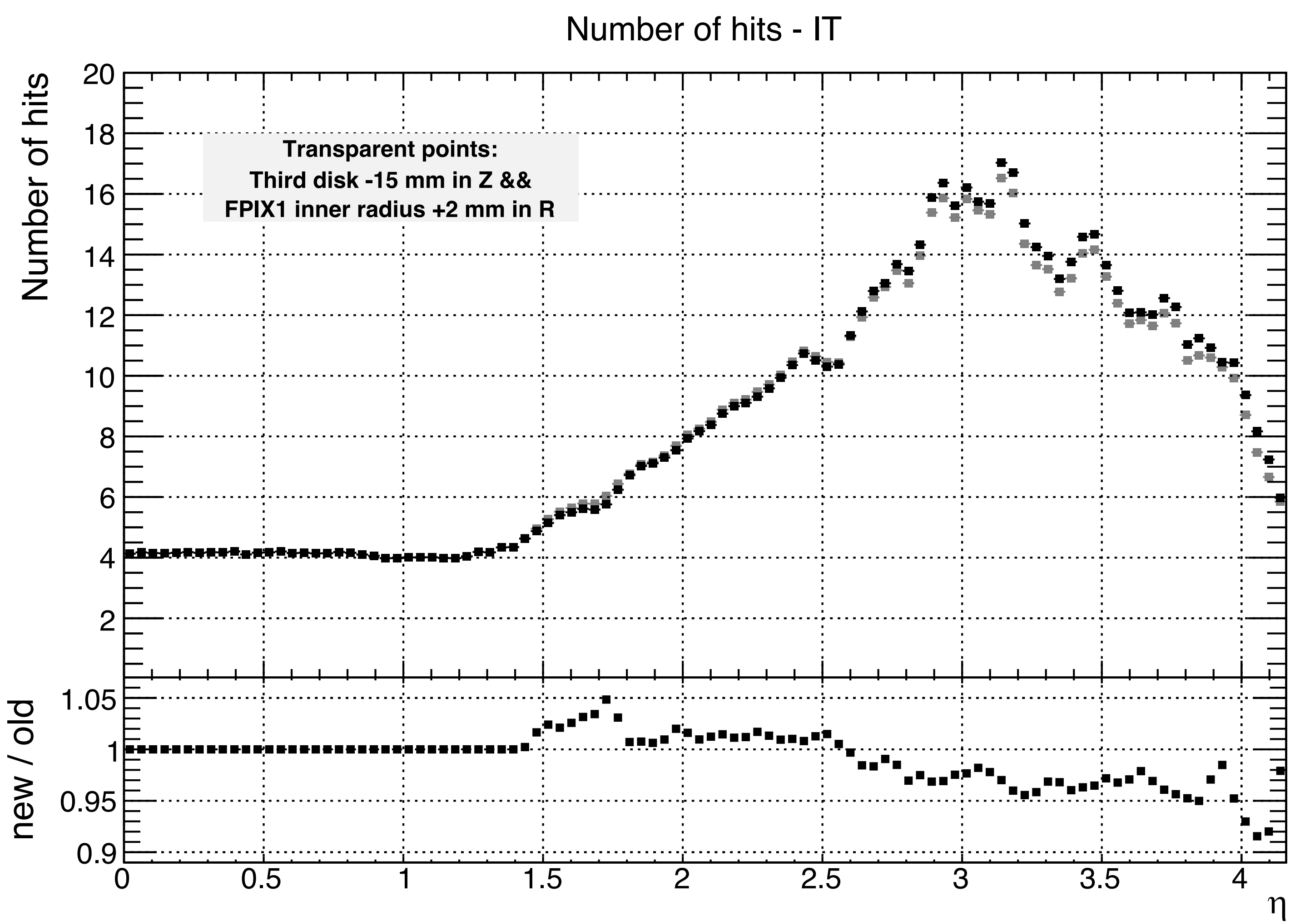
Third disk Z position: -15 mm



Inner ring radius shifted up in r by 2 mm (all disks)

COMPARISONS

Number of hits - IT



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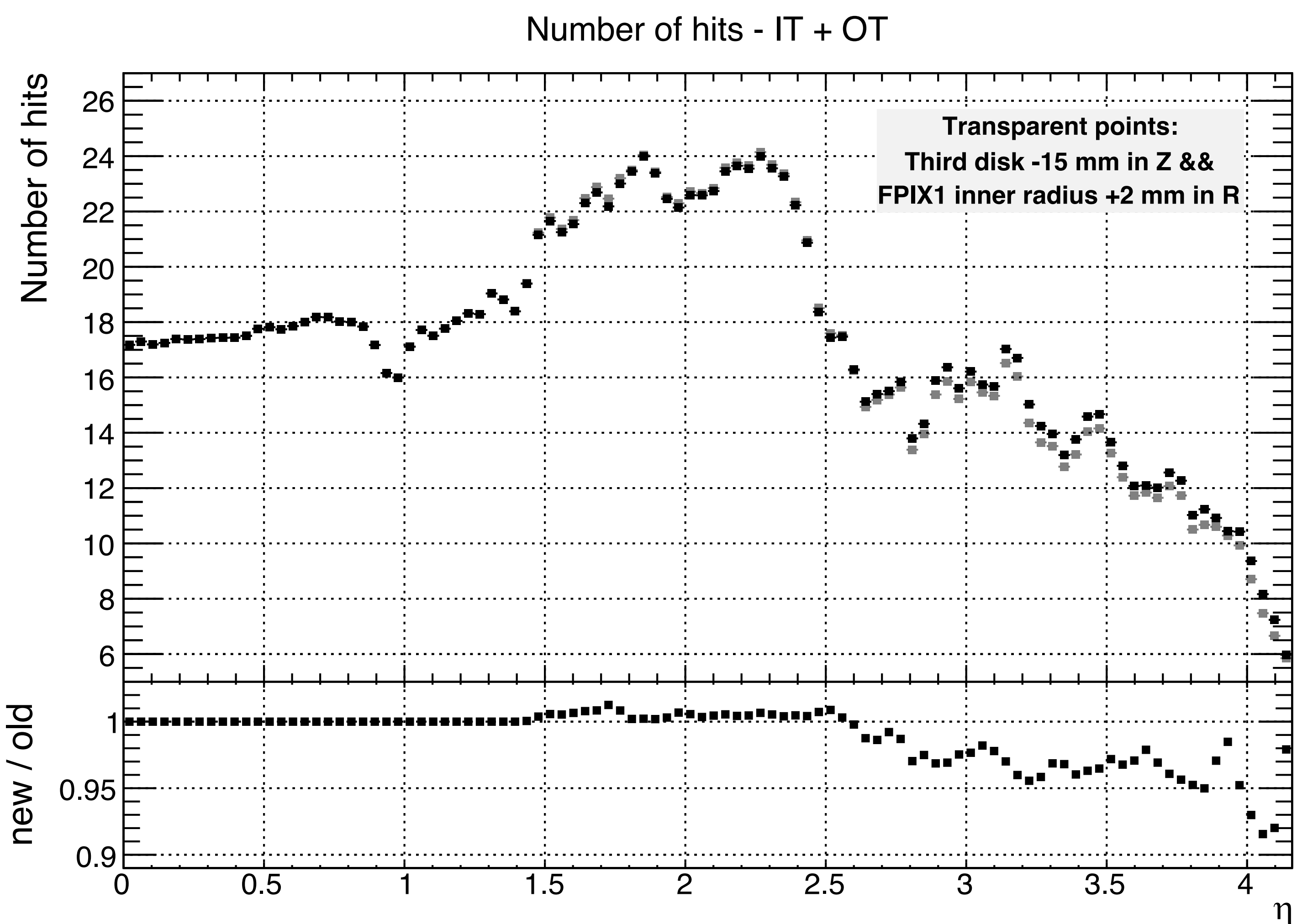
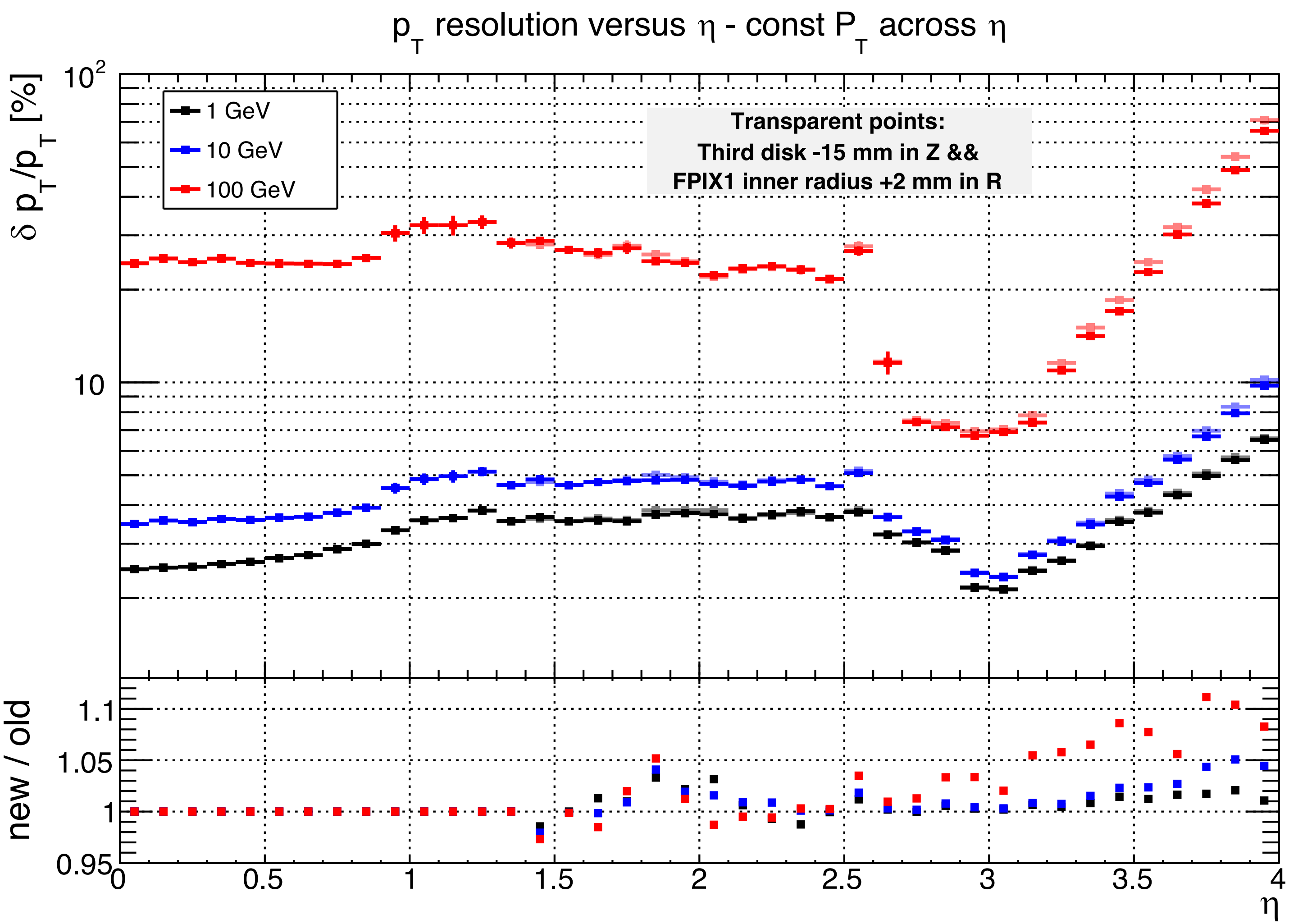
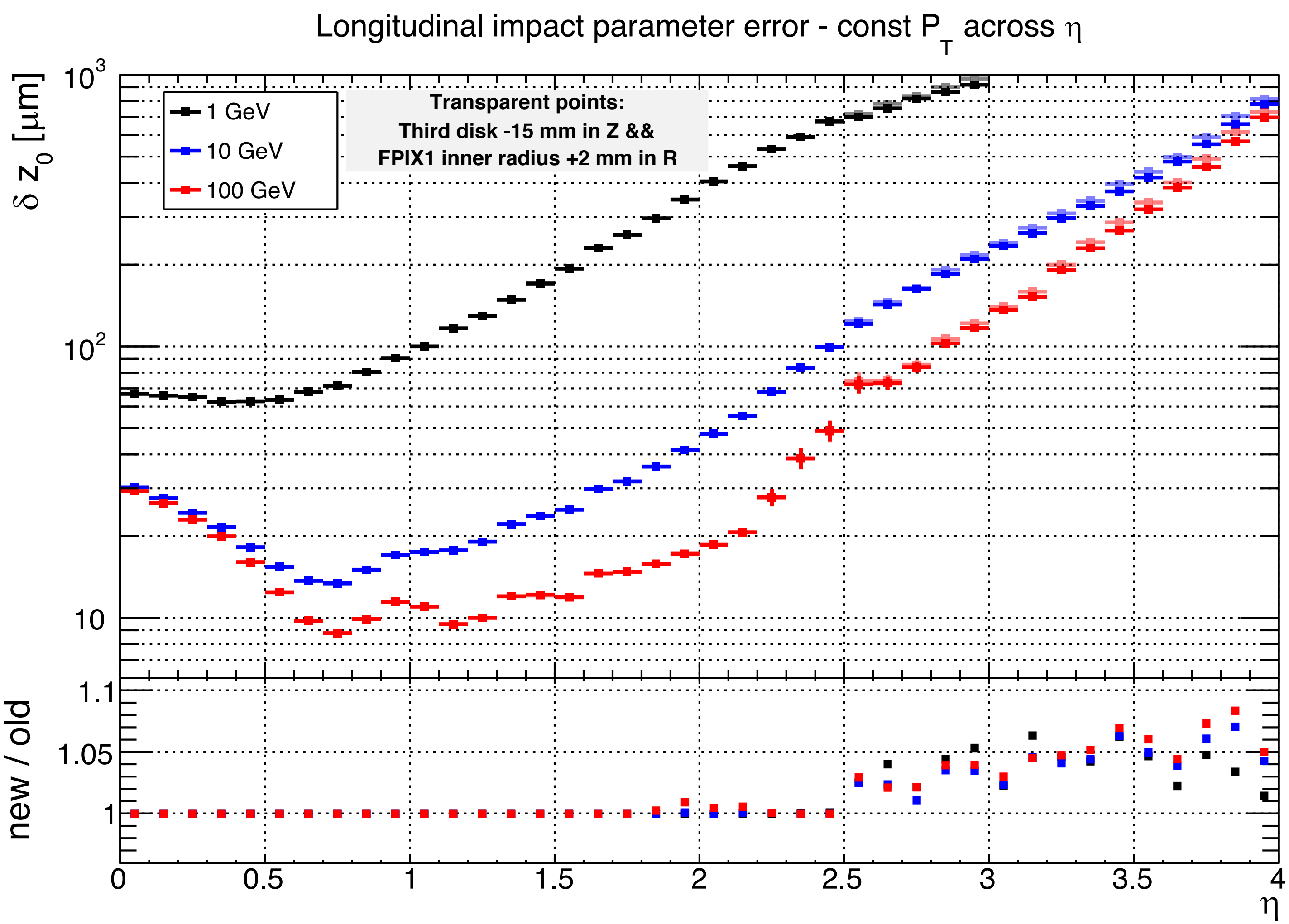
Number of hits – IT+OT



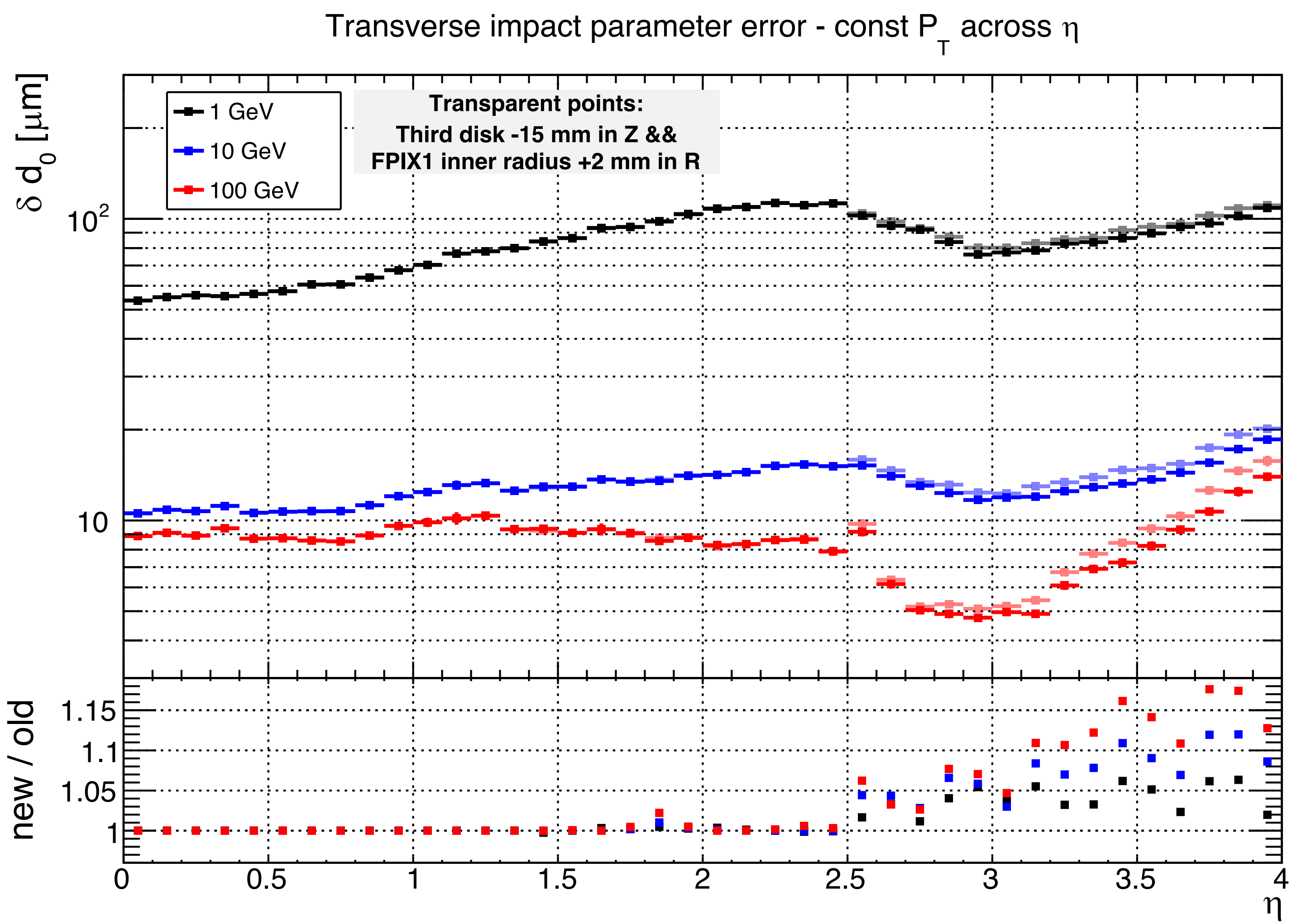
pT comparison



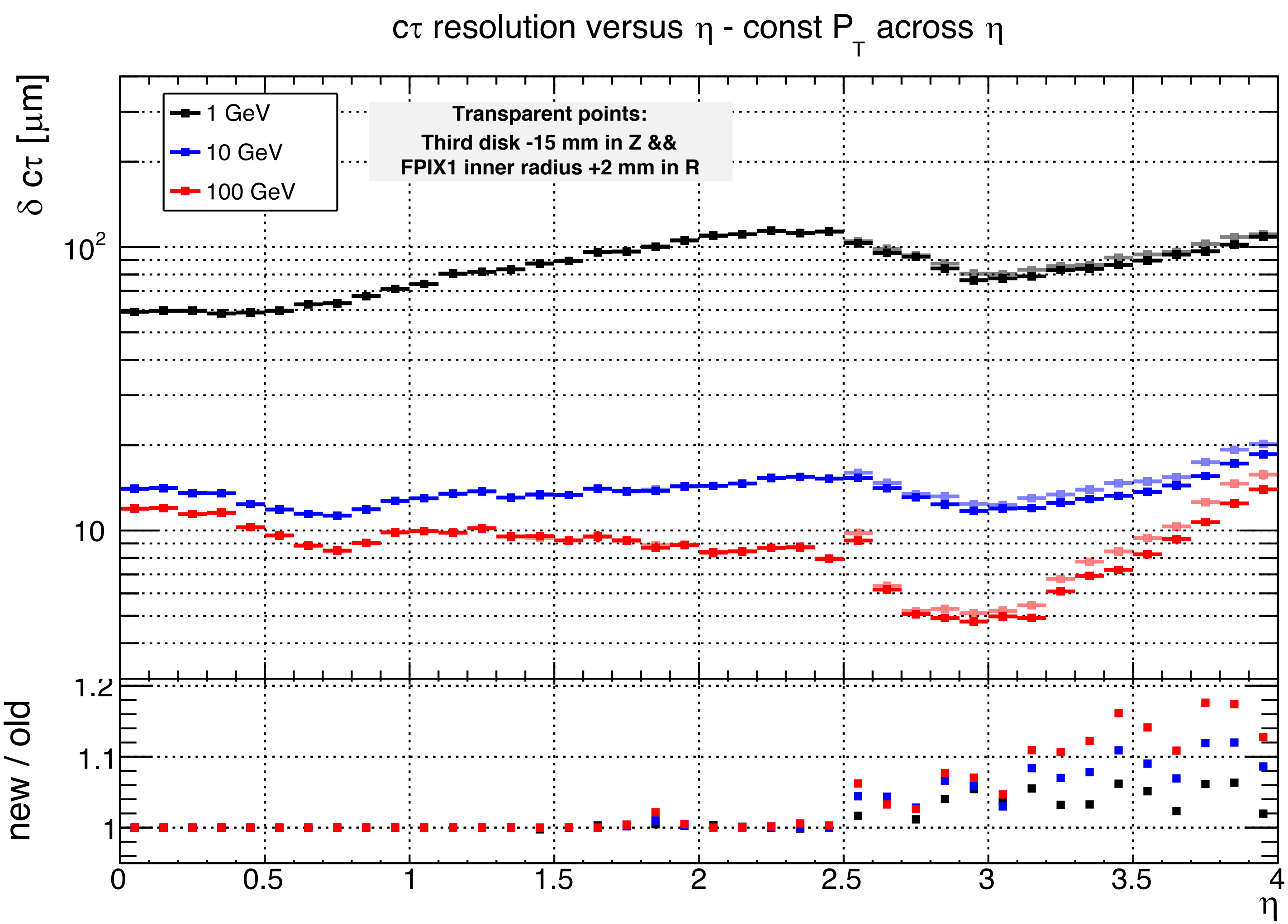
d_z comparison



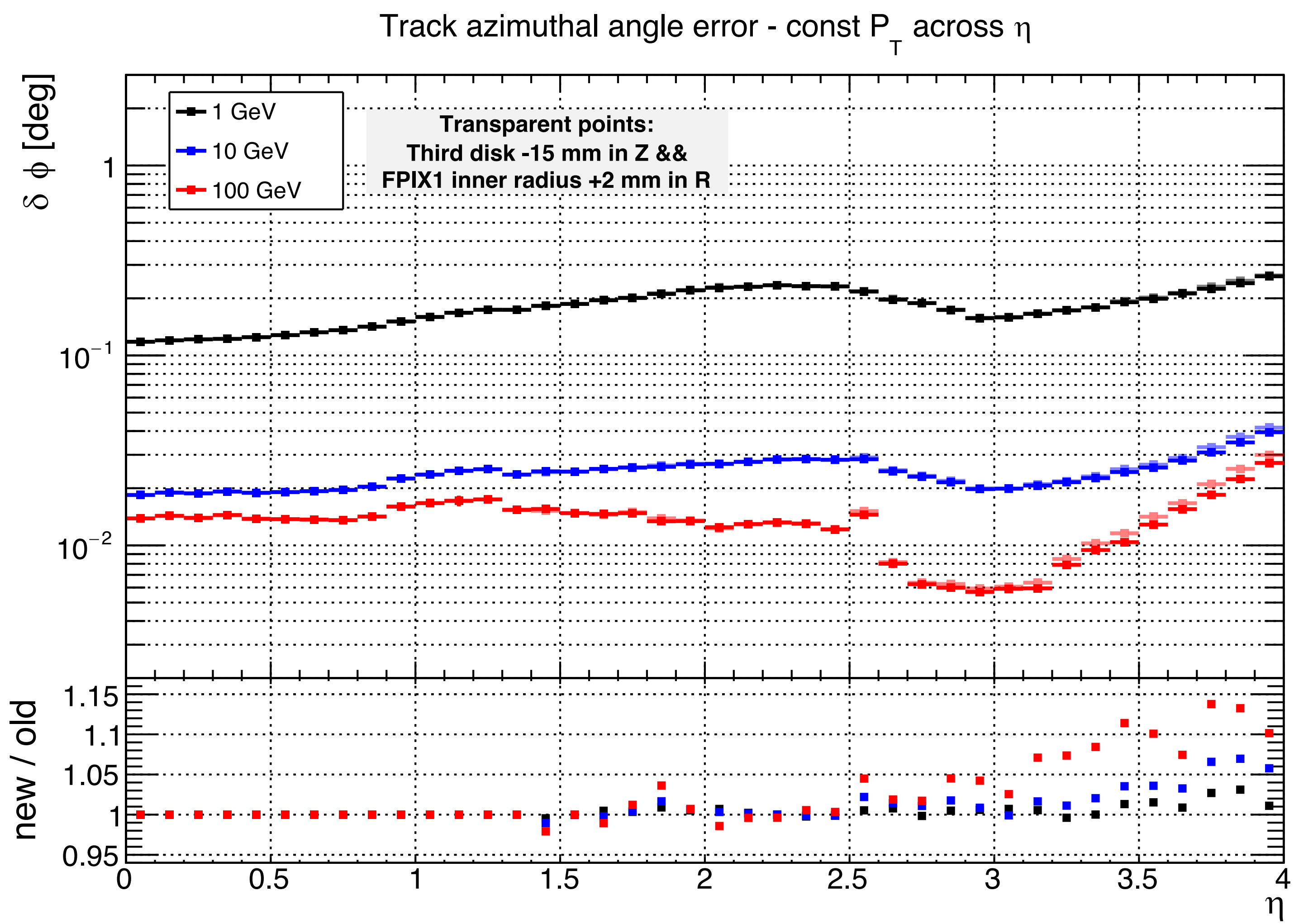
d_{xy} comparison



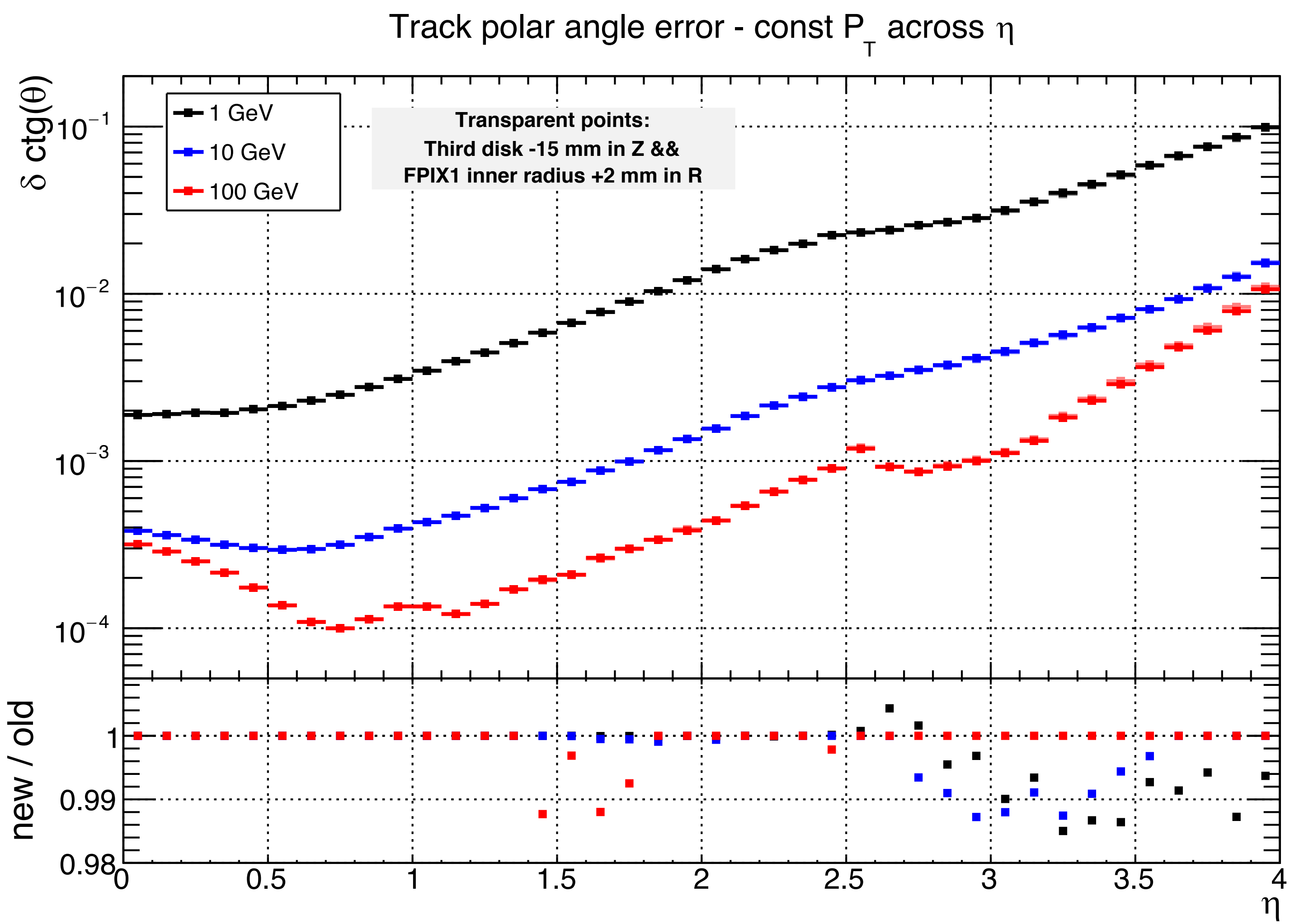
cτ comparison



ϕ error comparison



θ error comparison



Mechanics conclusions

- Biggest effect ~ 10-15% increase in d_{xy} resolution, for etas larger than about 2
- Almost similar effect in phi error
- Longitudinal resolution is less affected, by ~ 5% for eta > 2.5
- Similar effect for pT resolution
- Decrease in number of hits by up to 5% in forward region
- Important note: most of the effect due to inner radius change, not third disk Z (effects studied separately)
- So probably just have to live with it (installation clearance issue takes priority)

Tweaks in material

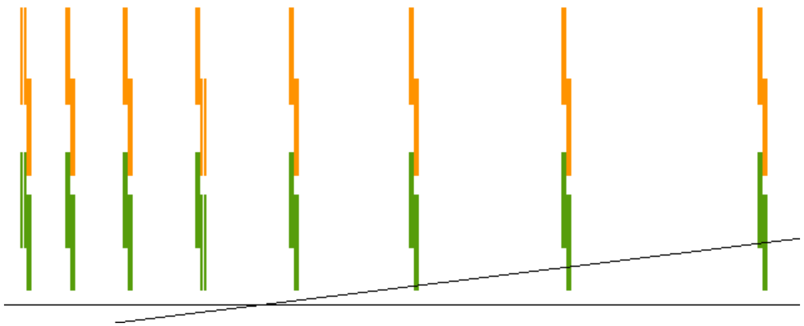
- TDR baseline specifies TFPX cooling tubes to be Titanium
- But Ti is expensive unfortunately
- If we can use Stainless Steel instead, might get some significant savings
- But SS is heavier and has higher radiation length
- Goal: verify effect of SS on radiation length and track resolution
- Also useful to have thermal conductivity studies (in progress)
- Studies shown here still not the most accurate in terms of material estimates; currently interfacing with Yadira to get there
- But again relative comparison still very useful

How tkLayout sees materials

- (step 1) Define geometries:
  - FPIX disk geometry
  - BPIX layer geometry
  - Support tube geometry
- (step 2) Attach amount of material to each geometry:
  - Cooling
  - Optical fiber components
  - CF
  - Etc
- (step 3) tkLayout automatically creates surfaces with corresponding geometries to determine material distribution

Example

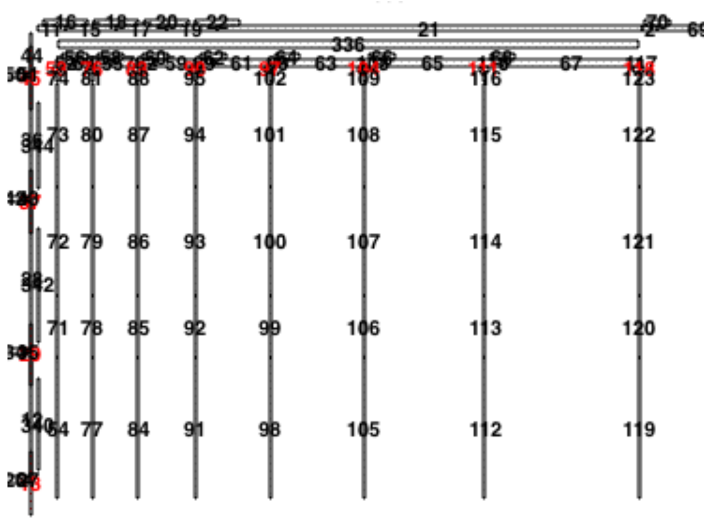
Step 1 – define geometry



Step 2 – attach material

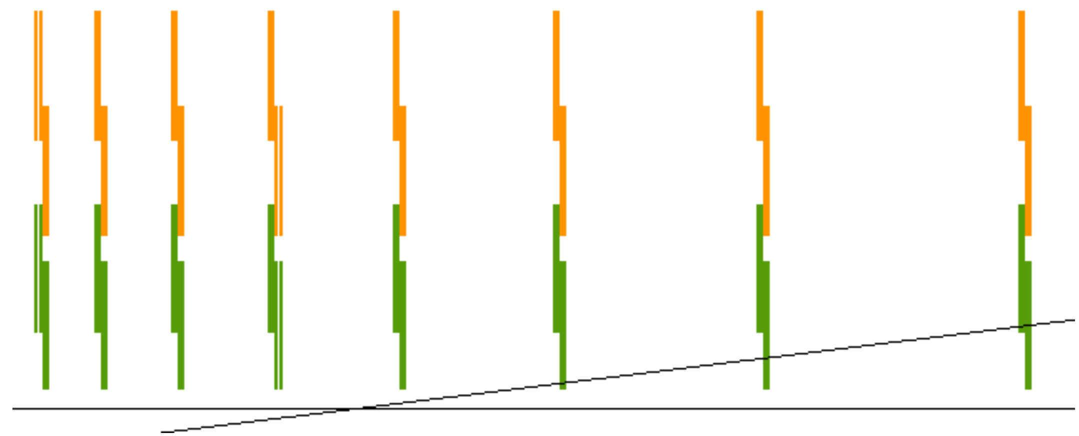
```
// Pixel endcap disks material
// Small disks (108 modules)

Materials FPIX_disk {
  type layer

  // Cooling for the module
  // Average on disk
  Component {
    componentName Cooling
    service false
    scaleOnSensor 0
    Element {
      elementName Ti
      quantity 10.21
      unit g
    }
    Element {
      elementName CO2
      quantity 9.69
      unit g
```

Step 3 – calculate material dist.



Example – step 1

```
      Ring 3 {
        @include-std CMS_Phase2/Pixel/ModuleTypes/pixel_2_2x2_25x100
        @includestd CMS_Phase2/Pixel/Materials/module_FPIX_v2_R3_2x2_2500
        @includestd CMS_Phase2/Pixel/Resolutions/Endcap_25x100
        numModules 24
        ringOuterRadius 127
      }
      Ring 4 {
        @include-std CMS_Phase2/Pixel/ModuleTypes/pixel_2_2x2_25x100
        @includestd CMS_Phase2/Pixel/Materials/module_FPIX_v2_R4_2x2_2500
        @includestd CMS_Phase2/Pixel/Resolutions/Endcap_25x100
        numModules 32
        ringOuterRadius 159.99
      }
      Disk 1 { placeZ 250.00 }
      Disk 2 { placeZ 319.76 }
      Disk 3 { placeZ 408.99 }
      Disk 4 { placeZ 523.11 }
      Disk 5 { placeZ 669.08 }
      Disk 6 { placeZ 855.78 }
      Disk 7 { placeZ 1094.57 }
      Disk 8 { placeZ 1400.00 }
```



Example —- step 2

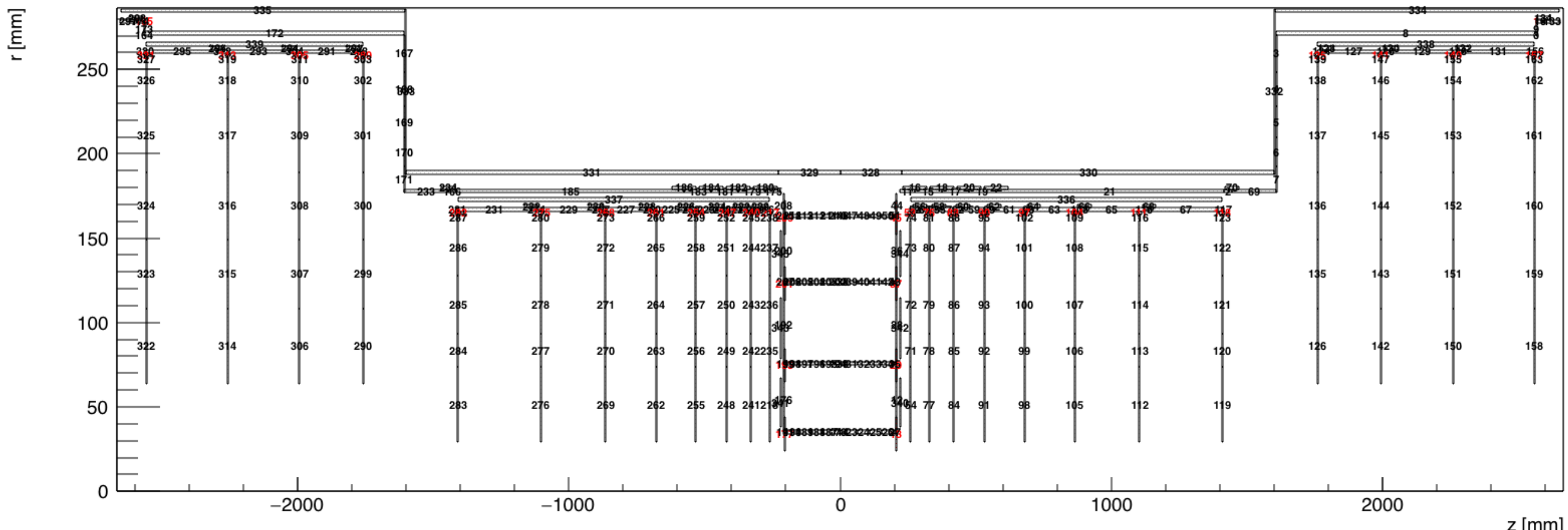
Disk material

```
// Pixel endcap disks material
// Small disks (108 modules)

Materials FPIX_disk {
  type layer

  // Cooling for the module
  // Average on disk
  Component {
    componentName Cooling
    service false
    scaleOnSensor 0
    Element {
      elementName Ti
      quantity 10.21
      unit g
    }
    Element {
      elementName CO2
      quantity 9.69
      unit g
```

Flange material

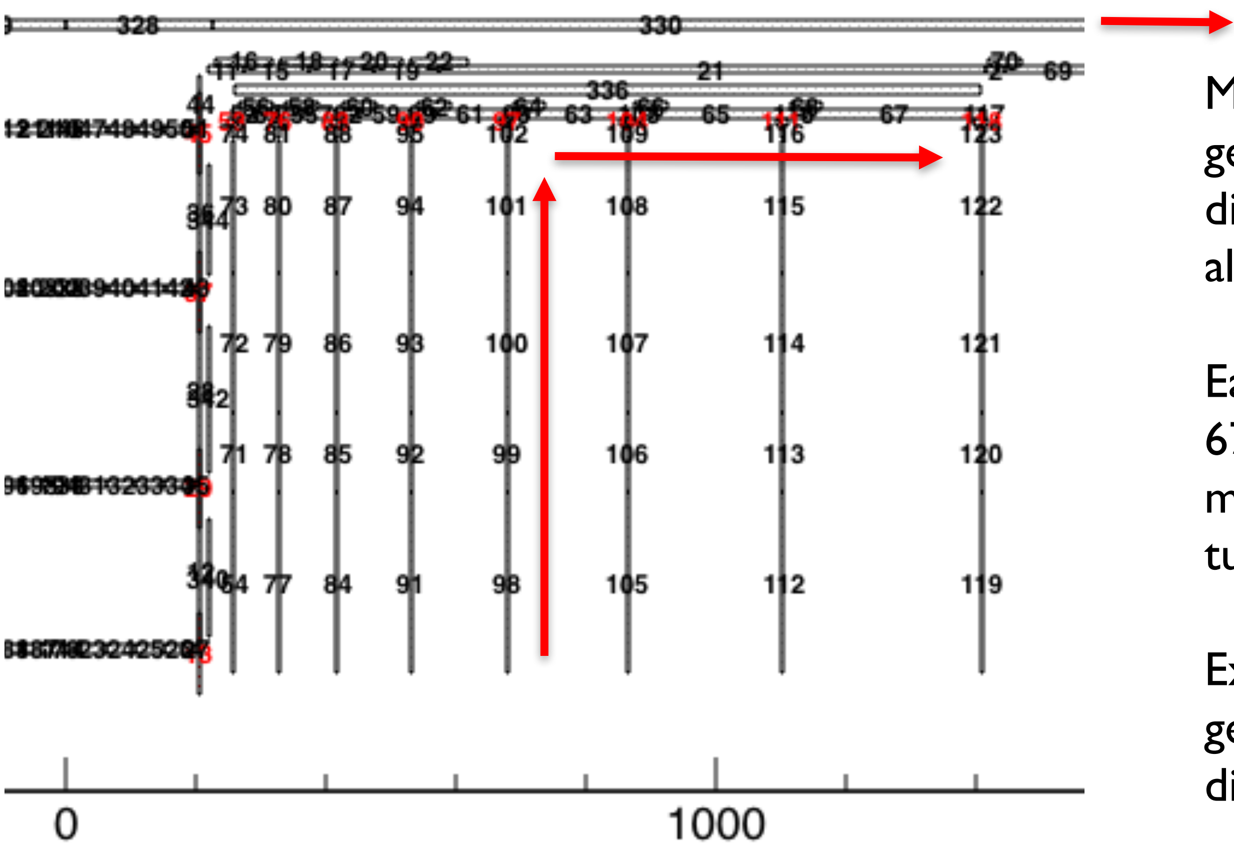
```
// Flange service conversion
// used to generate services at the FPIX flange

Station {
  stationName flange_FPIX
  type flange

  @include-std CMS_Phase2/Pixel/Conversions/Components/FPIX_Steel_1:1000
  @include-std CMS_Phase2/Pixel/Conversions/Components/FPIX_Ti_1:1000
  @include-std CMS_Phase2/Pixel/Conversions/Components/FPIX_Cu_1:1000
  @include-std CMS_Phase2/Pixel/Conversions/Components/FPIX_CO2_1:1000
  @include-std CMS_Phase2/Pixel/Conversions/Components/FPIX_Al_1:1000
  @include-std CMS_Phase2/Pixel/Conversions/Components/FPIX_Al_HV_1:1000
  @include-std CMS_Phase2/Pixel/Conversions/Components/FPIX_PE_1:1000

  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_Cu_TWP_1+1_HS
  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_Cu_TWP_1+1_LS
  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_Cu_TWP_1+1_HS_div4
  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_Cu_TWP_1+1_LS_div4
  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_Cu_TWP_2+1_HS
  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_Cu_TWP_3+1_HS
  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_Cu_TWP_6+1_HS
  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_Kapton
  @include-std CMS_Phase2/Pixel/Conversions/Components/propagate_PE
}
```

Example – step 3



1	serviceID/I	elementID/I	z1/D	z2/D	r1/D	r2/D	Element/C	mass/D	mass_per_length/D	rl/D	il/D	local/I
1127	106	13	864.355	866.355	73.657	93.26	Kapton	0.0301886	0.00154	0.00519372	0.00188743	1
1128	106	14	864.355	866.355	73.657	93.26	PE	1.41876	0.0723748	0.00519372	0.00188743	1
1129	106	15	864.355	866.355	73.657	93.26	Ti	1.48875	0.0759452	0.00519372	0.00188743	1
1130	107	0	864.355	866.355	93.36	127.967	Airex	5.7751	0.166877	0.00469714	0.00173514	1
1131	107	1	864.355	866.355	93.36	127.967	Al	3.42623	0.099004	0.00469714	0.00173514	1
1132	107	2	864.355	866.355	93.36	127.967	Al_HV	0.37583	0.0108599	0.00469714	0.00173514	1
1133	107	3	864.355	866.355	93.36	127.967	CF	16.2665	0.470036	0.00469714	0.00173514	1
1134	107	4	864.355	866.355	93.36	127.967	CO2	2.49438	0.0720773	0.00469714	0.00173514	1
1135	107	5	864.355	866.355	93.36	127.967	Cu	0.661564	0.0191165	0.00469714	0.00173514	1
1136	107	6	864.355	866.355	93.36	127.967	Cu_TWP_2+1_HS	0.734222	0.021216	0.00469714	0.00173514	1
1137	107	7	864.355	866.355	93.36	127.967	Cu_TWP_3+1_HS	0.611852	0.01768	0.00469714	0.00173514	1
1138	107	8	864.355	866.355	93.36	127.967	FPIX_Al	0.00330151	9.54E-05	0.00469714	0.00173514	1
1139	107	9	864.355	866.355	93.36	127.967	FPIX_Al_HV	0.00022149	6.40E-06	0.00469714	0.00173514	1
1140	107	10	864.355	866.355	93.36	127.967	FPIX_CO2	0.00089978	2.60E-05	0.00469714	0.00173514	1
1141	107	11	864.355	866.355	93.36	127.967	FPIX_Cu	0.00057448	1.66E-05	0.00469714	0.00173514	1
1142	107	12	864.355	866.355	93.36	127.967	FPIX_PE	0.00189646	5.48E-05	0.00469714	0.00173514	1
1143	107	13	864.355	866.355	93.36	127.967	FPIX_Ti	0.00092055	2.66E-05	0.00469714	0.00173514	1
1144	107	14	864.355	866.355	93.36	127.967	Kapton	0.116418	0.003364	0.00469714	0.00173514	1
1145	107	15	864.355	866.355	93.36	127.967	PE	2.50468	0.0723748	0.00469714	0.00173514	1
1146	107	16	864.355	866.355	93.36	127.967	Ti	2.62824	0.0759452	0.00469714	0.00173514	1
1147	108	0	864.355	866.355	128.067	160.738	Airex	7.11424	0.217754	0.00424965	0.0016165	1

Example – step 3



Material (e.g. cooling) gets routed up along disks, and then right along service cylinder

Each block of SC (63, 65, 67, …) adds more and more material since the tubes are piling up

Exactly 0.0266 g/m of Ti gets added to SC per disk

How tkLayout calculates X_0

- Take material budget from before
- Calculate X/X_0 for each surface (in previous plot):

$$N = X/X_0 = \sum_i \frac{m_i/A}{X_i}$$

(Sum over elements of surface: Ti, CO2, Cu, etc. A is area of surface)

- Run straight line from origin to different eta's, summing up X_0 from each surface along the way, scaled by eta angle (theta)
- Note: no 3D volumes in tkLayout, only surfaces. So can only estimate N directly, not X_0

Example

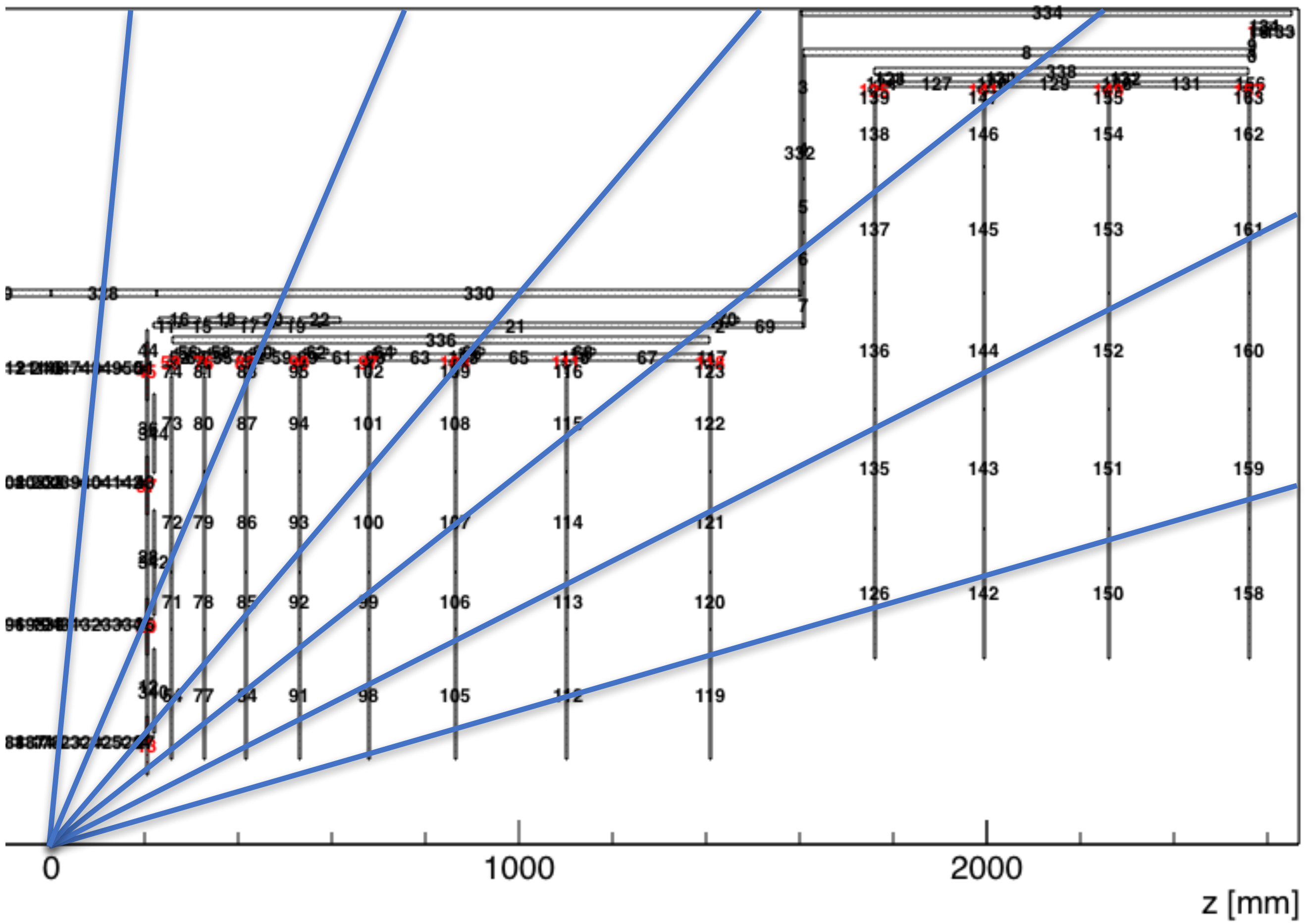
Ring material:
$X/X_0 = 0.0052$

1	serviceID/I	elementID/I	z1/D	z2/D	r1/D	r2/D	Element/C	mass/D	mass_per_length/D	rl/D	il/D	local/I
1127	106	13	864.355	866.355	73.657	93.26	Kapton	0.0301886	0.00154	0.00519372	0.00188743	1
1128	106	14	864.355	866.355	73.657	93.26	PE	1.41876	0.0723748	0.00519372	0.00188743	1
1129	106	15	864.355	866.355	73.657	93.26	Ti	1.48875	0.0759452	0.00519372	0.00188743	1
1130	107	0	864.355	866.355	93.36	127.967	Airex	5.7751	0.166877	0.00469714	0.00173514	1
1131	107	1	864.355	866.355	93.36	127.967	Al	3.42623	0.099004	0.00469714	0.00173514	1
1132	107	2	864.355	866.355	93.36	127.967	Al_HV	0.37583	0.0108599	0.00469714	0.00173514	1
1133	107	3	864.355	866.355	93.36	127.967	CF	16.2665	0.470036	0.00469714	0.00173514	1
1134	107	4	864.355	866.355	93.36	127.967	CO2	2.49438	0.0720773	0.00469714	0.00173514	1
1135	107	5	864.355	866.355	93.36	127.967	Cu	0.661564	0.0191165	0.00469714	0.00173514	1
1136	107	6	864.355	866.355	93.36	127.967	Cu_TWP_2+1_HS	0.734222	0.021216	0.00469714	0.00173514	1
1137	107	7	864.355	866.355	93.36	127.967	Cu_TWP_3+1_HS	0.611852	0.01768	0.00469714	0.00173514	1
1138	107	8	864.355	866.355	93.36	127.967	FPIX_Al	0.00330151	9.54E-05	0.00469714	0.00173514	1
1139	107	9	864.355	866.355	93.36	127.967	FPIX_Al_HV	0.00022149	6.40E-06	0.00469714	0.00173514	1
1140	107	10	864.355	866.355	93.36	127.967	FPIX_CO2	0.00089978	2.60E-05	0.00469714	0.00173514	1
1141	107	11	864.355	866.355	93.36	127.967	FPIX_Cu	0.00057448	1.66E-05	0.00469714	0.00173514	1
1142	107	12	864.355	866.355	93.36	127.967	FPIX_PE	0.00189646	5.48E-05	0.00469714	0.00173514	1
1143	107	13	864.355	866.355	93.36	127.967	FPIX_Ti	0.00092055	2.66E-05	0.00469714	0.00173514	1
1144	107	14	864.355	866.355	93.36	127.967	Kapton	0.116418	0.003364	0.00469714	0.00173514	1
1145	107	15	864.355	866.355	93.36	127.967	PE	2.50468	0.0723748	0.00469714	0.00173514	1
1146	107	16	864.355	866.355	93.36	127.967	Ti	2.62824	0.0759452	0.00469714	0.00173514	1
1147	108	0	864.355	866.355	128.067	160.738	Airex	7.11424	0.217754	0.00424965	0.0016165	1

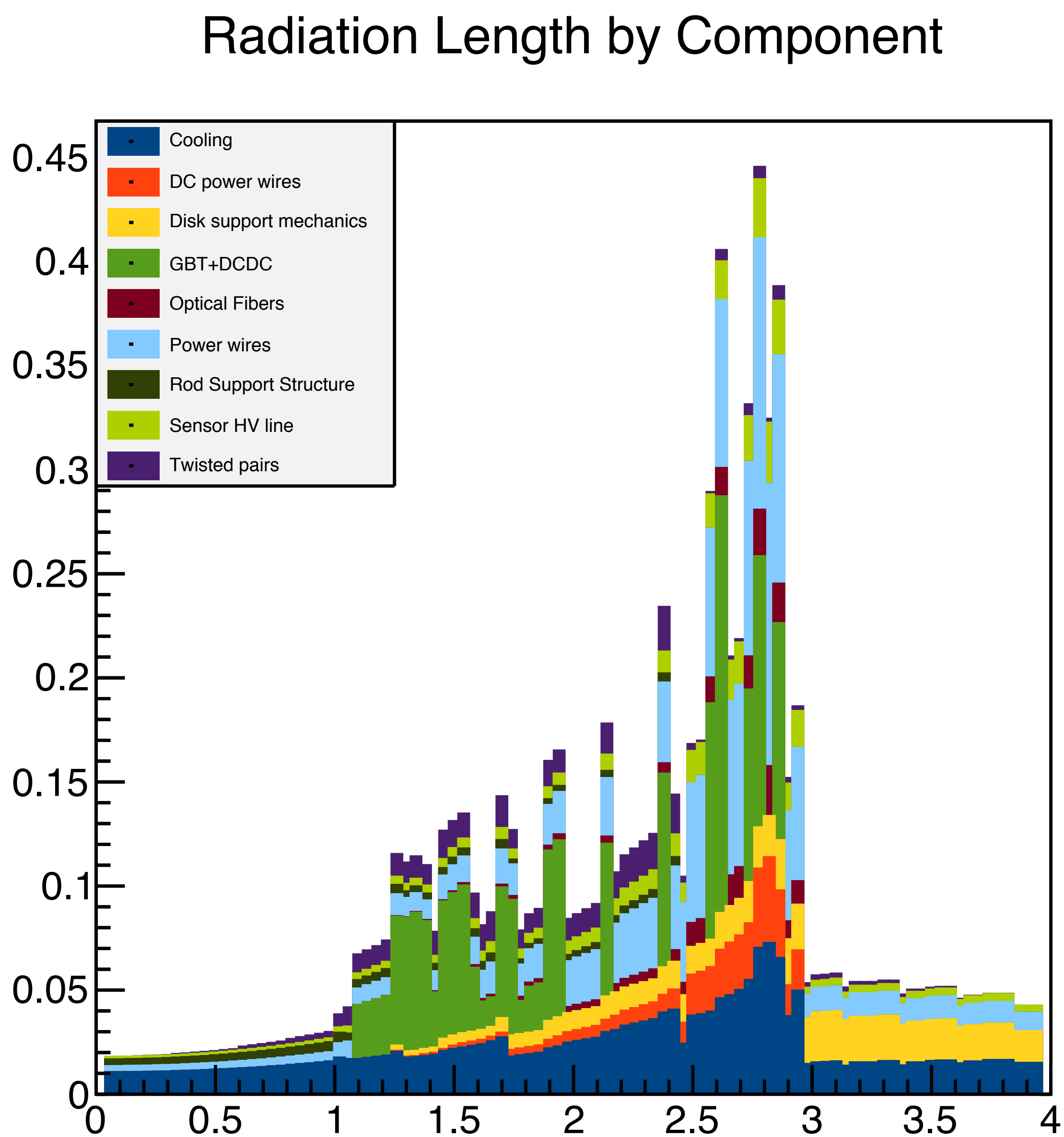
Ring material:
$X/X_0 = 0.0047$

Ring material:
$X/X_0 = 0.0042$

Example



Example


Radiation Length by Component
Cooling
DC power wires
Disk support mechanics
GBT+DCDC
Optical Fibers
Power wires
Rod Support Structure
Sensor HV line
Twisted pairs
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
2.5
3
3.5
4

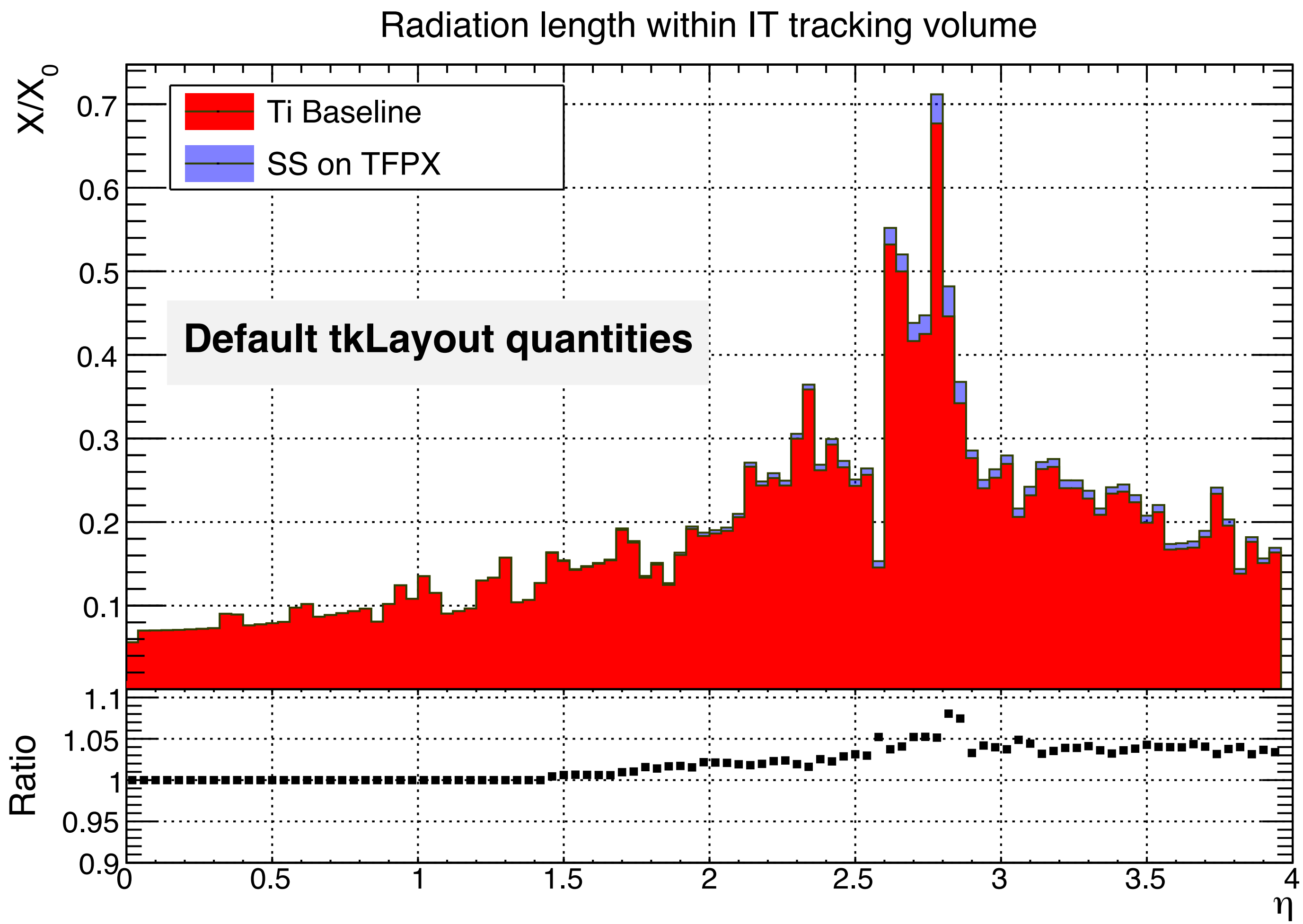
Ti → SS

- For this study, simply replace Ti by SS, accounting for density difference
- Use same volumes, so that:

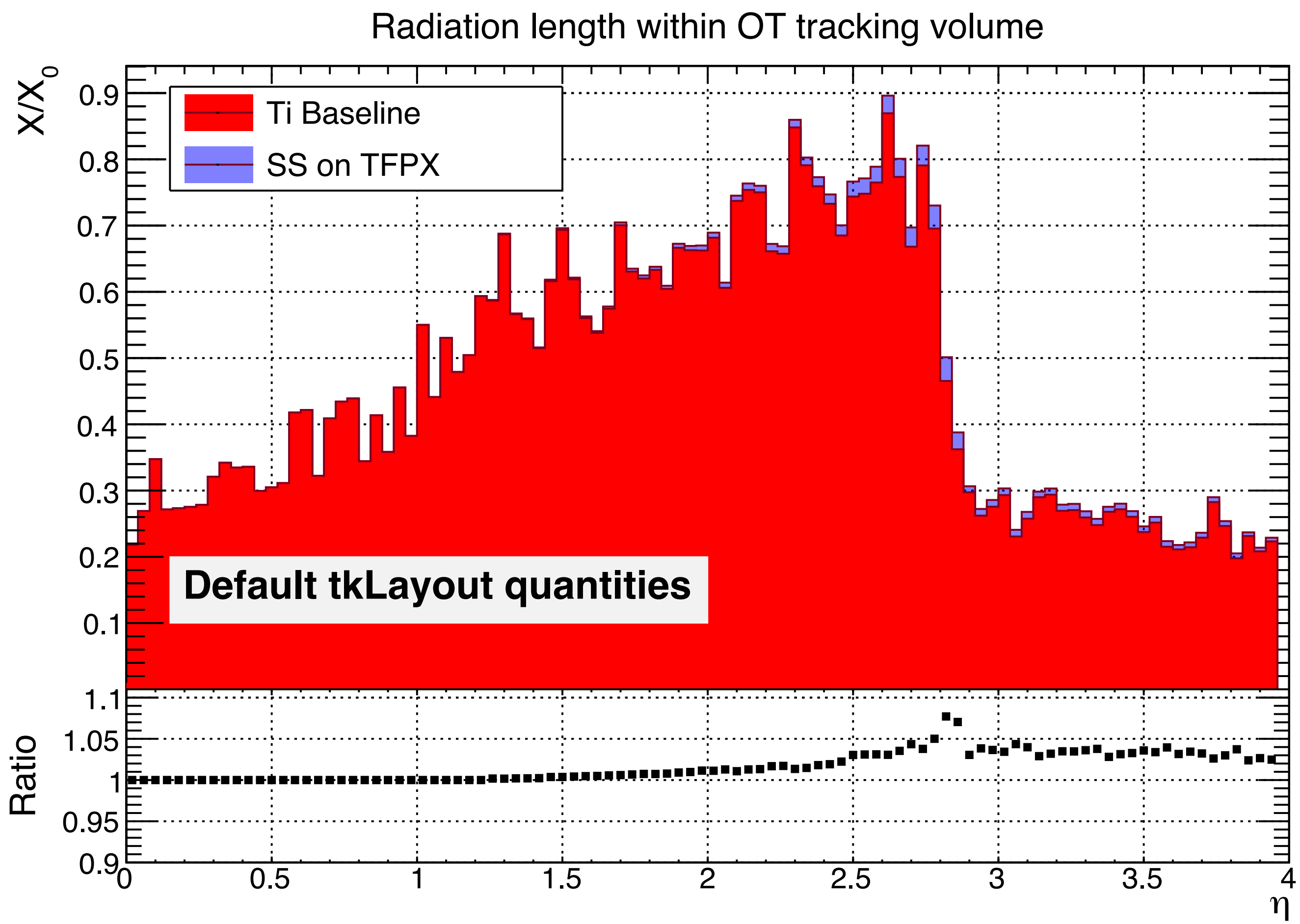
$$\frac{\rho_{\mathrm{SS}}}{\rho_{\mathrm{Ti}}} = 1.78 \Rightarrow m_{\mathrm{SS}} = m_{\mathrm{Ti}} \times 1.78$$

- Then run tkLayout material and R. L. analysis
- Doesn't use dee specs yet, only default tkLayout specs

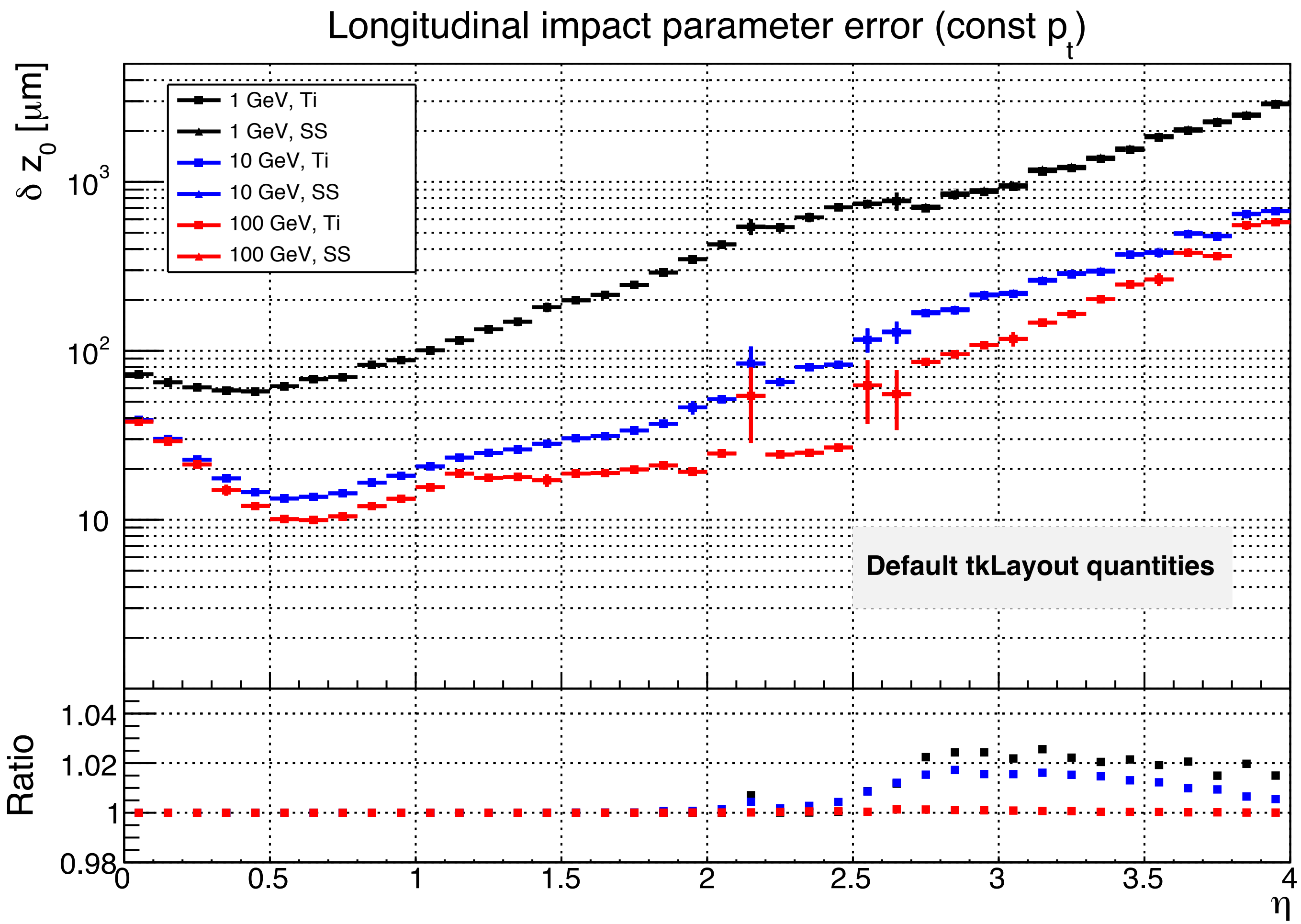
Ti → SS (IT)


Radiation length within IT tracking volume
X/X_0
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Ti Baseline
SS on TFPX
Default tkLayout quantities
Ratio
1.1
1.05
1
0.95
0.9
0
0.5
1
1.5
2
2.5
3
3.5
4
η

Ti → SS (TI+OT)


Radiation length within OT tracking volume
X/X_0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Ti Baseline
SS on TFPX
Default tkLayout quantities
Ratio
1.1
1.05
1
0.95
0.9
0
0.5
1
1.5
2
2.5
3
3.5
4
η

d_z error


Longitudinal impact parameter error (const p_t)
δ z_0 [μm]
10^3
10^2
10
1 GeV, Ti
1 GeV, SS
10 GeV, Ti
10 GeV, SS
100 GeV, Ti
100 GeV, SS
Default tkLayout quantities
Ratio
1.04
1.02
1
0.98
0
0.5
1
1.5
2
2.5
3
3.5
4
η

Material conclusions

- Change from Ti → SS on TFPX seems to roughly double cooling $N = X/X_0$
- This translates to a 4-5% increase on average in total RL for eta > 2.5
- Also translates to a 2-3% change in z0 resolution
- This study assumes the TDR material estimates
- Other previous studies estimated a more accurate material distribution based on dee mechanics
- However, not showing here since soon I'll have the latest and greatest estimates for material, so will re-do studies more accurately

Next steps

- Investigate different module width (+400 microns per module)
- Estimate accurate material budget based on up-to-date mechanics
- Run fullsim study (CMSSW) of cumulative changes to get an even better sense of the performance

Previous studies

- Link to previous studies with separate effects and introduction to the installation clearance issue:
  - https://cmshead.mps.ohio-state.edu:8080/VFPix/231 - Inner Radius verification (+2mm in R) in tkLayout
  - https://cmshead.mps.ohio-state.edu:8080/VFPix/235 - Inner Radius verification (+2mm in R) in CMSSW
  - https://cmshead.mps.ohio-state.edu:8080/VFPix/240 - Moving third disk in Z by -15mm (tkLayout)
  - https://cmshead.mps.ohio-state.edu:8080/VFPix/229 - Extended Luminous region verification in tkLayout